



AGE-WELL National Innovation Hub
Centre national d'innovation d'AGE-WELL

Sensors and Analytics for Monitoring Mobility and Memory
Capteurs et analytique de suivi mobilité-mémoire

Enabling Aging-in-Place: Supportive Smart Home Solutions

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Santé
Bruyère
Health

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University 

What does Aging in Place mean?

- Older adults having **the ability and option** to continue to live in the residence of **their choice** safely.
- This raises a number of distinct questions that are the foundation for our work
 - What does it mean for a home to enable aging in place?
 - Cognitive Health
 - Physical Health
 - General Health
 - What about privacy?

The SAM³ founders

Bruyère (Bruyère Health Research Institute and Bruyère Health)

Carleton University

AGE-WELL National Centre of Excellence.

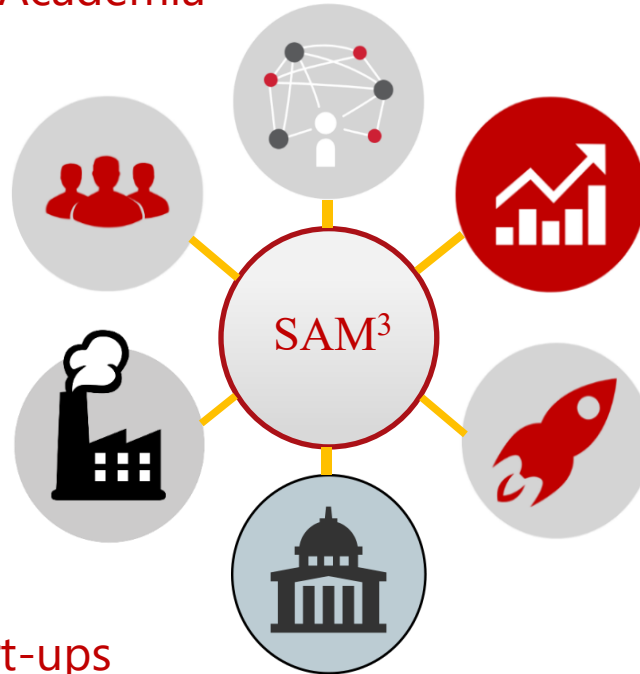
Inter-Disciplinary Partnerships

Researchers / Academia

End-users: Older Adults
& Caregivers

Mature Companies

Start-ups



Healthcare Providers
Community Care
Providers

Public Sector & Providers



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Health



Supportive Smart Home Technology



What is a Supportive Smart Home?

Smart Home technology is everywhere

- Used to turn lights on/off with a voice command.

- Used to automate heating/cooling.

- Used for home security and many other applications

- Enable communications and engagement!

Does this really enable independence or aging in place?



How can we use this technology support independence?

- Must address wide range of need/use models

- Can we use these sensors placed around the home with smart software systems to support independence?

- How can we expand on its capability?



COST: Widespread use has helped reduced technology costs significantly

High electronic packaging density:

- Apple A17: 19,000,000,000 transistors (3 nm technology)

Ability to incorporate Micro Electro Mechanical Systems (MEMS):

- Accelerometers, Gyroscopes, Miniaturized Motors

Wireless connectivity:

- Wi-Fi, 5G, BT, BLE, Zigbee, RFID, NFC

These advances led to the introduction of a new generation of chips with low energy consumption, high processing power and broad wireless connectivity.

What are Sensors?

- **Sensors measure input from surrounding (light, heat, humidity, smell, taste, acceleration, pressure, electrical signals, EM wave, ...)**
- **Characteristics:**
 - ⇒ Usually very small in size (mm)
 - ⇒ Extremely low cost (a few cents)
 - ⇒ Minimal power consumption (m Watt)
 - ⇒ Wireless connectivity (BLE, WiFi, Zigbee)
- **Used in industry to improve functionality and save money:**
 - ⇒ Smart Phones; Health Care; Security; Home Appliances; Smart Homes;
 - ⇒ Manufacturing; Cars; Airplane;



Sensors are everywhere now

- Typical Smartphone

- Microphone (sound)
- Camera (image/video)
- Gyroscope (orientation)
- Accelerometer (motion)
- Light (day/night)
- Magnetometer (compass)
- LiDAR (focus assist)

- Home security system / automation

- Motion sensors (IR)
- Glass Break (sound)
- Door/Windows (Latch sensors)
- Smoke detectors
- CO detectors
- Water detectors
- Automated lights
- Automated thermostats

- Automobile

- Back-up cameras
- Lane departure/position cameras
- Proximity sensors
- GPS and navigation
- Velocity sensors
- Acceleration sensors
- + all the engine sensors
- + even more if you own a Tesla!

- Medical

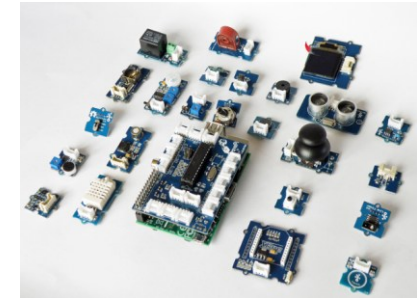
- Pulse Oximeter
- Glucometer
- Thermometer
- Blood Pressure
- Weight and BMI

- Hearing Aids

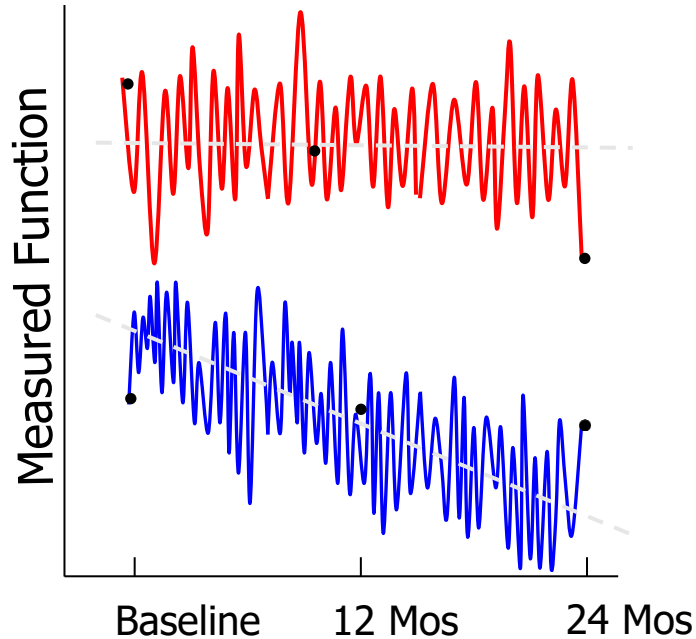
- Microphone (sound)
- Gyroscope (orientation)
- Accelerometer (motion)

- Fitbit

- Accelerometer (motion)
- Pulse Oximeter
- EEG (Heart Rate)
- etc



Why Sensors: Infrequent clinical assessment



Higher frequency data collection

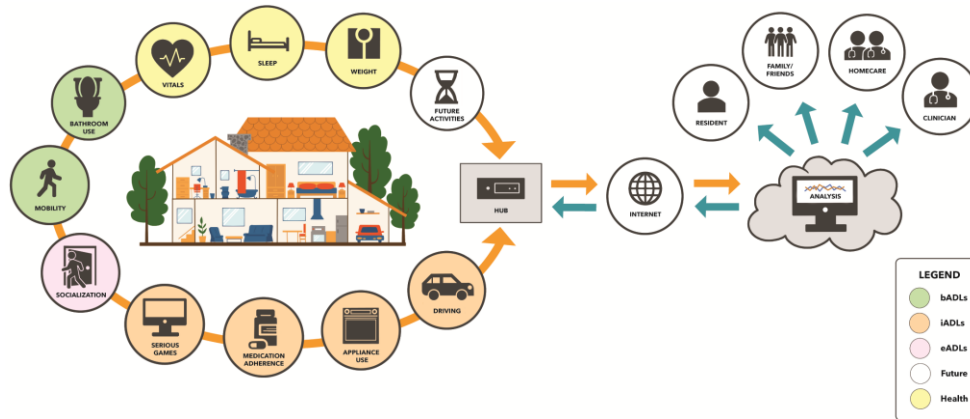
- improve accuracy
- detect variability

Cognitive decline

- Slow and day to day variable
- Can be hidden / subtle

Bringing Assessment Home

Unobtrusive, Home-Based Assessment of Everyday Activity and Function



It is NOT just about the data

- Needs based systems
- Data → knowledge
- Knowledge feedback to older adult can support independence

Aging Well

- Deniz and his wife Isra celebrated 53 years of marriage last year, but sadly, Isra suddenly passed away 6 months ago, and he has been missing her greatly. Isra was the fabric of their social life; she organized all their family gatherings, planned their annual get-away to Florida, and even set up weekly social events (e.g., neighborhood café meet-ups) with friends and neighbors. While many have called and popped over to keep him company, he noticed these had been trailing off in the last few months. **He realizes that he needs to find ways of staying connected on his own now. Isra was always the one comfortable with technology.** She was their 'emailer,' and she would regularly get on their iPad and video chat with friends and family across Canada, Turkey, and the USA. He missed seeing the gang from Florida.



Digital Literacy



Connected Canadians

How We've Helped

Connected Canadians has worked with thousands of seniors and has been described as a “lifeline” by people we have impacted. Connected Canadians has been successful in providing solutions-oriented mentorship to older adults in one-on-one mentorship.



It's opened up the world essentially. It's enabled me to connect with a family member that I had not seen with my eyes for five years... and this was made possible by Connected Canadians.

Our Approach

All of Connected Canadians' Technology Mentors are trained to be empathetic and collaborative when working with older adults.

1

Focus on building relationships between older adults and mentors

2

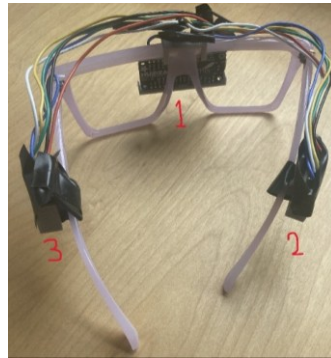
Learn technology together

3

Meet people where they are with their digital literacy skills

Hearing Aids as Mobility Sensors

- Many older adults require hearing aids due to hearing loss
- Accelerometers in hearing aids can be used for mobility assessment
- Hearing aids more likely to be worn than fitness watches as they have a primary function



True	walking	running	sitting	lying	up stairs	down stairs
	1311	9	32	0	87	13
	26	1417	0	0	9	0
	4	0	1439	1	6	2
	0	0	436	1016	0	0
	2	0	0	0	1450	0
	5	0	3	0	0	1444
Predicted						
	walking	running	sitting	lying	up stairs	down stairs



Early Mobility Challenges

- Antonio is struggling with climbing the stairs to his upstairs bedroom. **He has daily walks to the local grocery store, but this too is getting harder. He has fallen twice in the last 6 months while working in his garden.** His daughter worries about her father's mobility and what could happen when he falls and can't get back up.
- A year later, Antonio has stopped walking to the store; he either takes a taxi or waits until the weekend when Gabriella can drive him. A stair lift has been installed so that on days when Antonio is having more difficulty, he doesn't need to climb the stairs to go to bed. **However, Antonio is showing some unsteadiness while standing, for instance in the kitchen doing dishes.**



Sit to Stand – Pressure mats

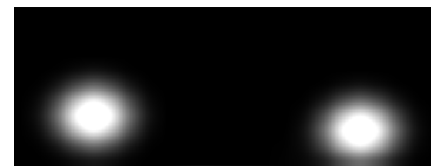
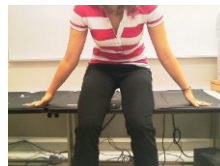
- Bed exit provides a daily sit to stand transition
- Changes in mobility can include
 - Speed
 - Failed exits
 - Bouncing/Rocking
 - Increased use of hands
 - Asymmetry
- Video analytics of pressure sequence video allows daily assessment



Hip pressure region



Hip and hand pressure regions



Hand pressure regions

Sleep

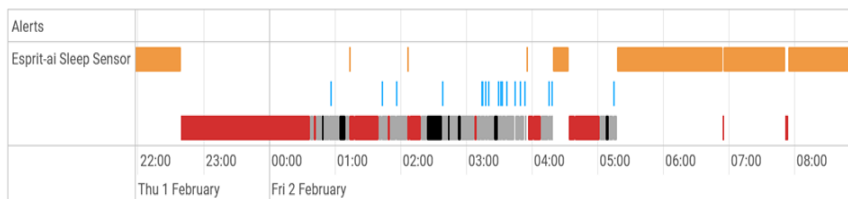
- Unobtrusive sensing either under mattress or bed leg.
- Presence in bed
 - Nocturia (day night reversal)
 - Frequently up at night (UTI)
- Starting to also include
 - Respiration and Heart rate
 - Sleep state



Under leg



Under Mattress

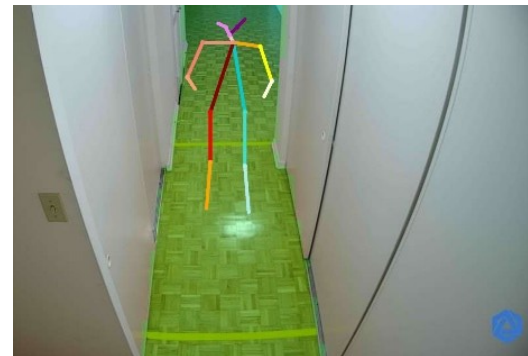


Walking Speed - Privacy respecting camera

- Camera provides 18-point stick-figure for a person in image and NOT actual video
- We are using the camera to provide ways to measure activity that respects privacy!
 - Measure gait speed for subject walking down hallway
 - Understanding kitchen activity
 - May have other applications for bed exit assessment.



AltumView



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Power Use with Integrated Sensing

- Outlets and switches with integrated Smart Home functions
 - Ability to control switch/outlet
 - Ability to detect if outlet in use
 - Optional sensor insert (motion, odors, gases, temperature, humidity and night light)
- Kitchen safety application
 - Can detect if appliances are left on
 - Remote shut off through app

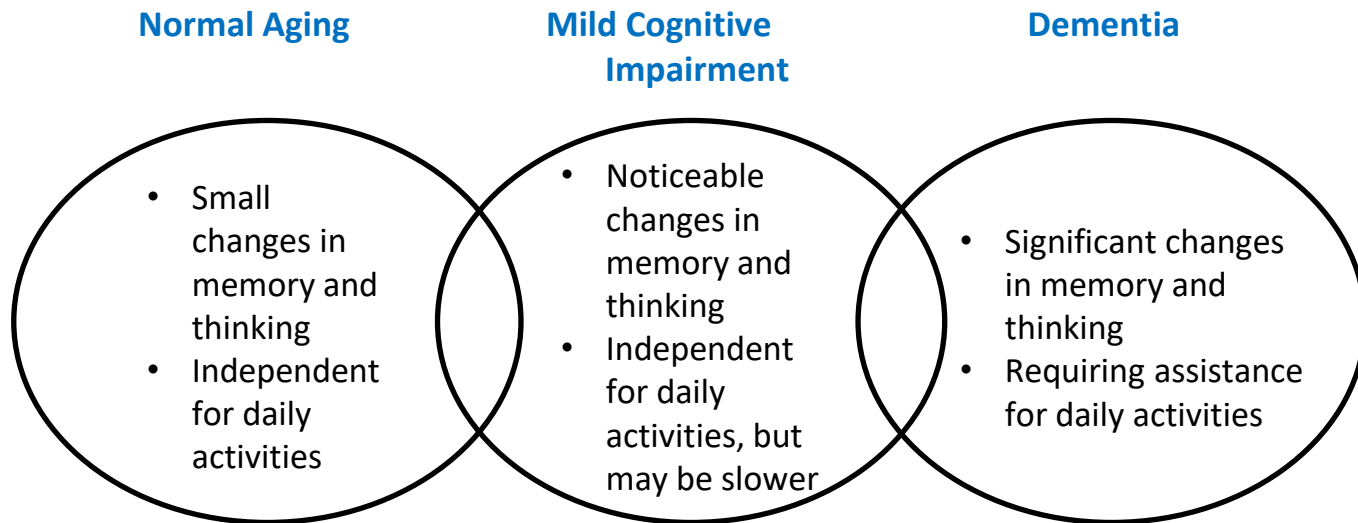


Early Cognitive Challenges

- After her diagnosis, Josette has maintained that she plans to live alone for as long as possible. Her friends and her doctor are worried about how quickly her cognition may decline. They have observed mild changes in her ability to complete daily tasks, such as missing some activities arranged with friends. Overall, she is still able to complete her instrumental activities of daily living (iADL), such as managing finances on a computer, doing her shopping, and making meals independently. Although her friends are able to check in on her, she is not visited on a day-to-day basis. **Her friends and formal caregivers would like to find ways to monitor for declines in her cognition that may indicate she is requiring additional assistance.**



Normal Aging versus Cognitive Impairment



Dementia Risk reduction

Diet

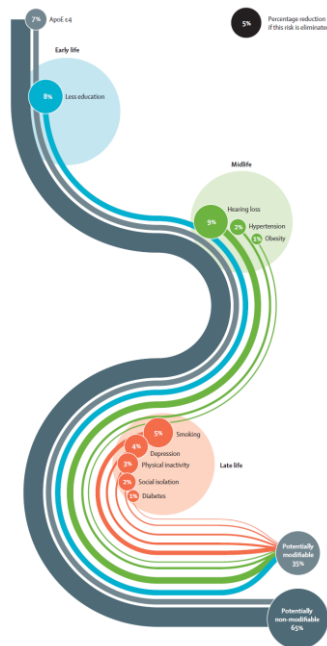
- Mediterranean diet
- increasing fruit/vegetable intake

Physical Exercise

- recommend physical activity interventions of at least moderate intensity to improve cognitive outcomes among older adults

Hearing

- audiology assessment and treatment if indicated



Livingston et al. The Lancet, 2016

Sleep

- treat sleep apnea

Cognitive training and stimulation

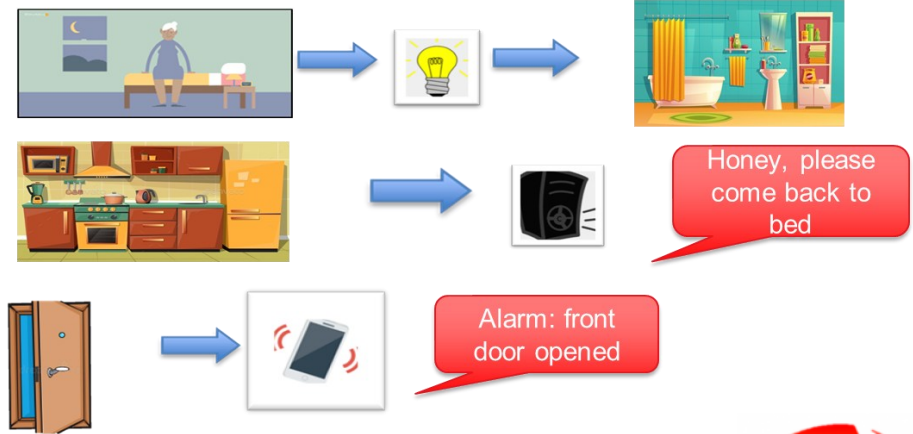
- no specific programs endorsed
- recommend a variety of cognitive stimulating activities

Medications

- minimize anti-cholinergic medications
- consider alternatives for depression, neuropathic pain, urinary incontinence

An Example – Wander Detection and Diversion (WDD)

- A Person Living with Dementia and Care Partner
- Night wandering (disorientation)
 - Risk to PLWD
 - Care Partner sleep affected
- Supportive Smart Home that (re)directs PLWD allowing Care Partner to rest



Results

- **Results: Anxiety and Depression**
 - **Before the intervention**
 - **After the intervention**



"It's a very important thing because it gives you peace of mind."

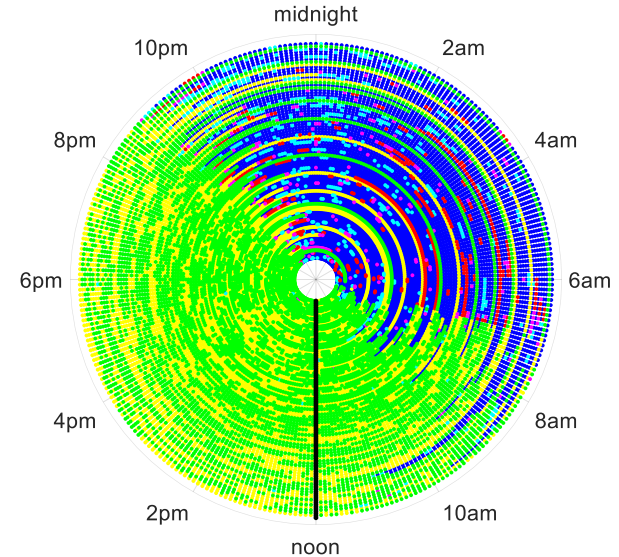
"I just bring my phone in, and I don't have to worry"

"I have more freedom now to do personal stuff knowing that I will be notified if she opens the front door."

"I just wish we could have kept it"

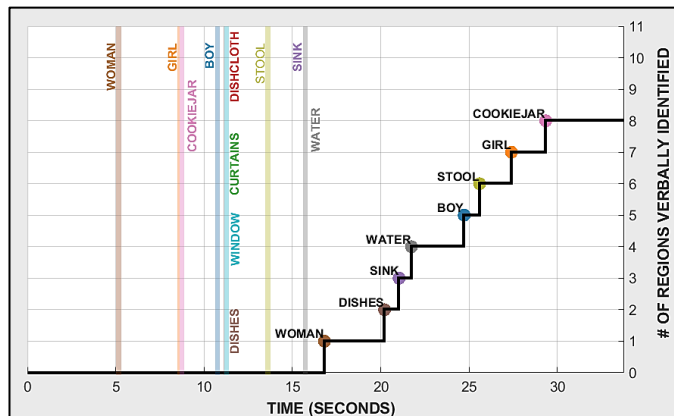
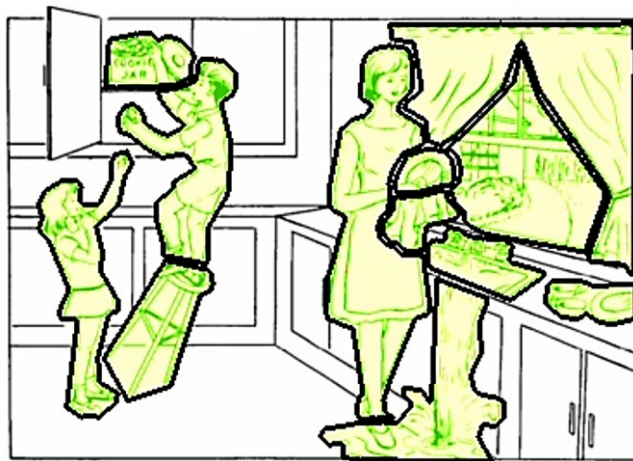
But there is a lot of information in the data

- Just looking at WDD data we can easily see
 - When they are in-bed or not
 - When they are in the washroom
 - That they go away most weekends
 - Go to bed at 9pm, rise around 7
 - etc
- Knowledge derived from these datasets can
 - Help to identify changes earlier
 - Allowing action before they become acute



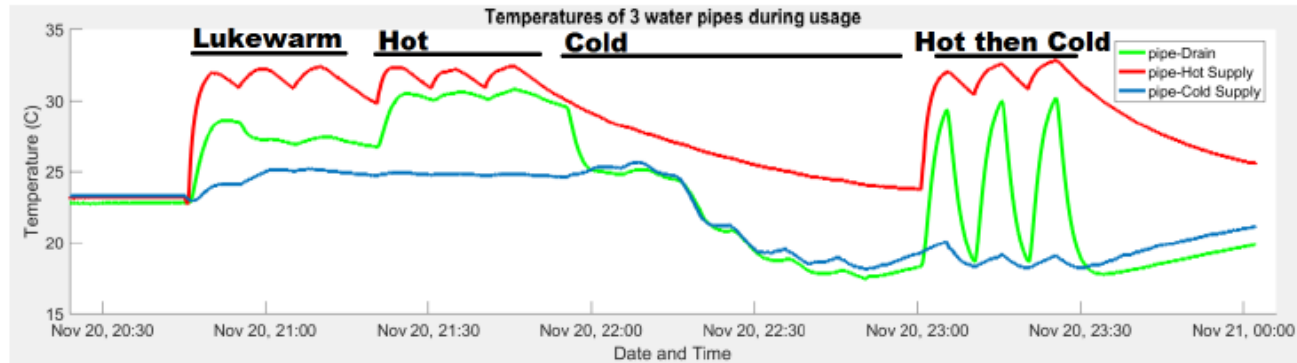
Speech and Eye

- Synchronized assessment of eye tracking with speech analysis
 - Provides indication of cognitive change
- Cookie Jar picture
 - When does a person view each region of interest (if at all)
 - When do they mention the region of interest (if at all)



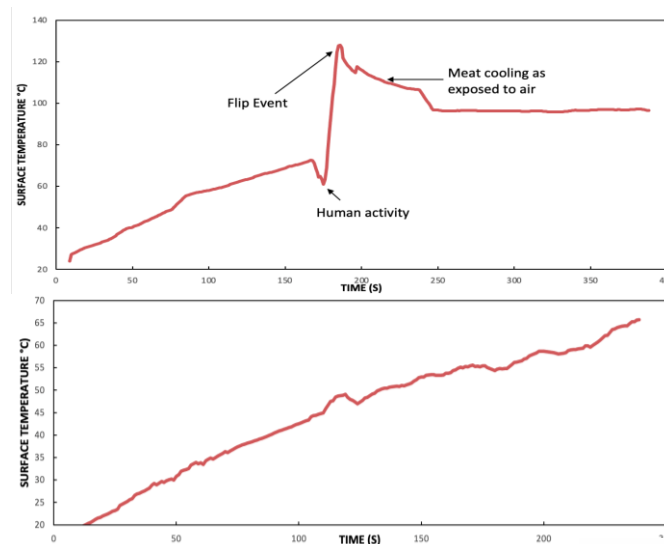
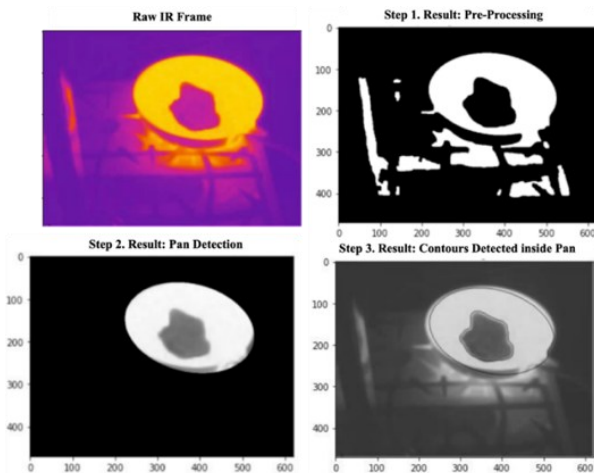
Water Use – Temperature Sensor

- Temperature sensors on supply and drain lines for sink
- Easily applied to pipe externally vs adding some form of flow meter.



Appliance Use – Thermal Camera

- Safety – stove left on etc
- Advance analysis of nutrition
 - Meal complexity
 - Cooking behaviours



**COOKTOP
SAFETY**
SAFE SMART COOKING



Driving

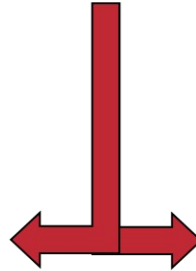


■ Driving Measures

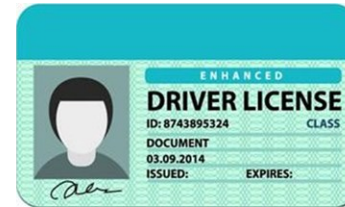
- Velocity, Acceleration, Jerk
- GPS
- Time of Day
- Weather

Health Status

-  ☒ Poor
☐ Average
☐ Excellent



Driving Fitness



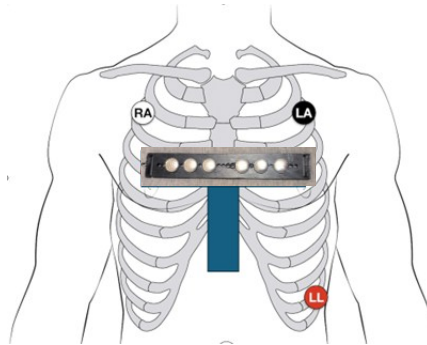
Medical Conditions

- Michaela Schmidt is a 72-year-old retired police officer in Berlin, Germany. She lives alone in a condo. **Four years ago, she suffered a severe heart attack and has struggled with congestive heart failure ever since.** Her cardiologist works at the Charité Universitätsmedizin Berlin Hospital.

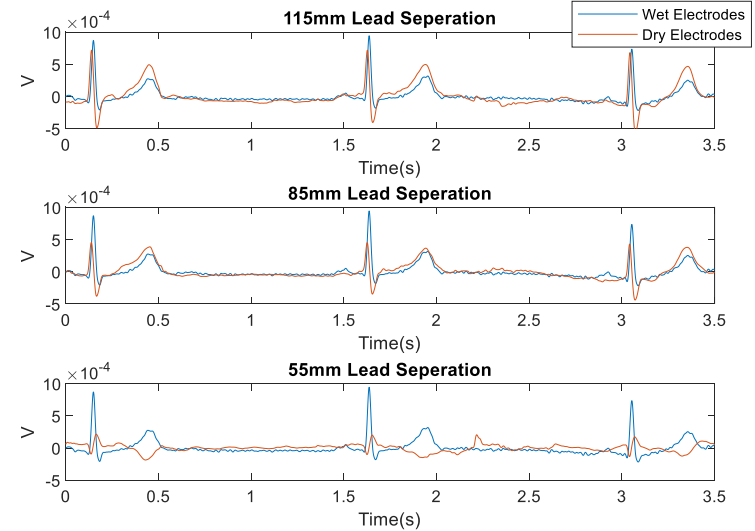


Heart Rate

- Support vital sign collection at home
- ECG measurement using a handheld device?
 - Size: ~ computer mouse



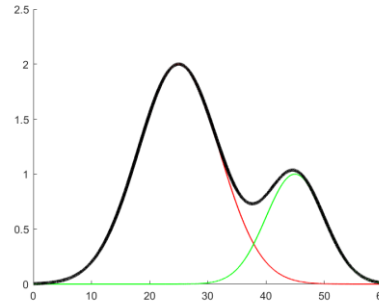
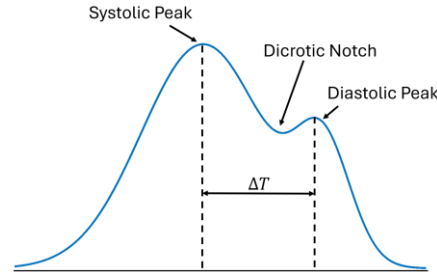
ECG Signal from 3 Measurement Points



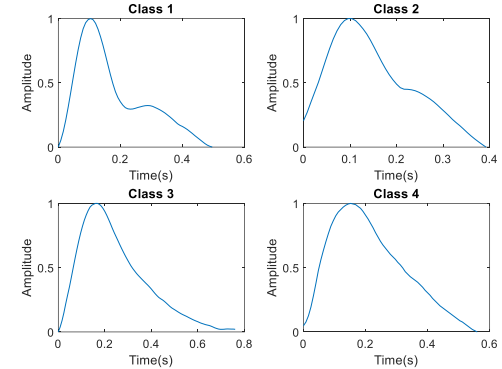
Arterial Health

The shape and duration of the wave can indicate several markers of health including:

- Heart rate
- Blood pressure
- Vascular age
- Arterial elasticity



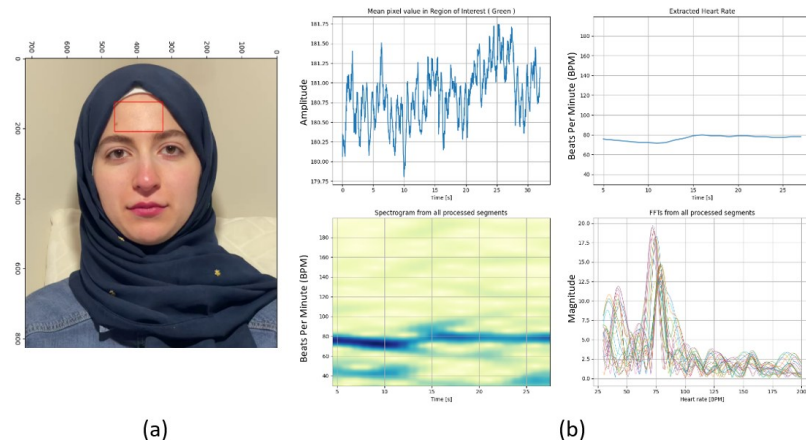
4 Different Classes of PPG Signals From MIMIC-III Dataset



PPG Signal Class	Average MSE	Amplitude Ratio
1	0.000898	0.364±0.096
2	0.000414	0.505±0.441
3	0.00295	0.169±0.355
4	0.00614	0.526±0.397

Heart Rate – Colour Video

- Pulse causes
 - Skin motion where arteries located close to skin surface (wrist)
 - Skin colour shift through the pulse wave as capillaries have flowing blood and then empty
- Video magnification
 - Can enhance skin motion to allow it detection leading to beat detection
 - Can enhance colour shift through pulse wave
 - Typically, best shown within green colour band. It is detectable but less prevalent in red.



Heart Rate – Thermal Video

- Video magnification can also be applied to thermal video to also detect the beat level events
- Advantage
 - Does not require light to work!
 - Is not affected by skin tone

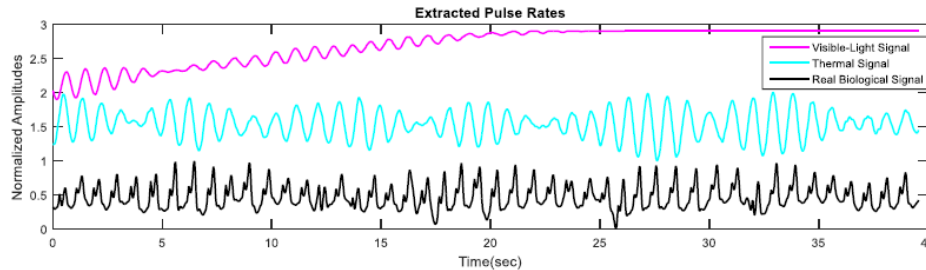


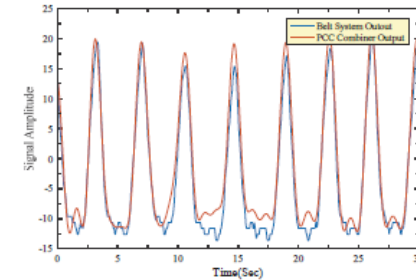
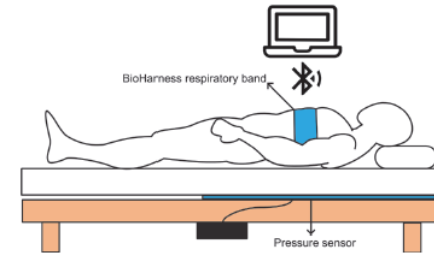
Fig. 2. Depiction of the thermal video ROI



Respiration Rate

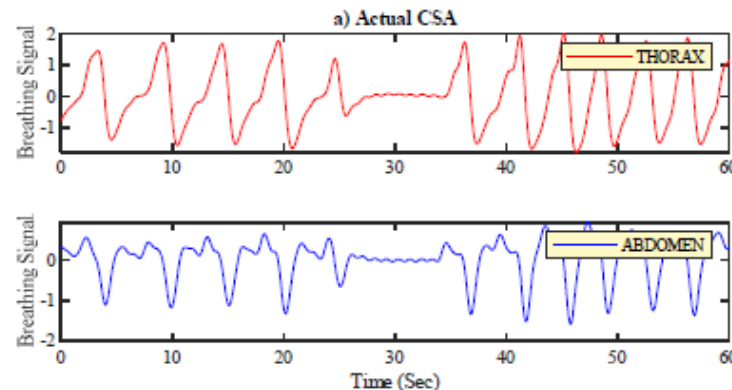


- Pressure sensitive mat deployed under the mattress
- Can detect pressure changes associated with chest and abdomen motion associated with breathing
 - Note in some positions, chest and abdomen changes are in opposite direction.
- Resulting ability to detect each breath event



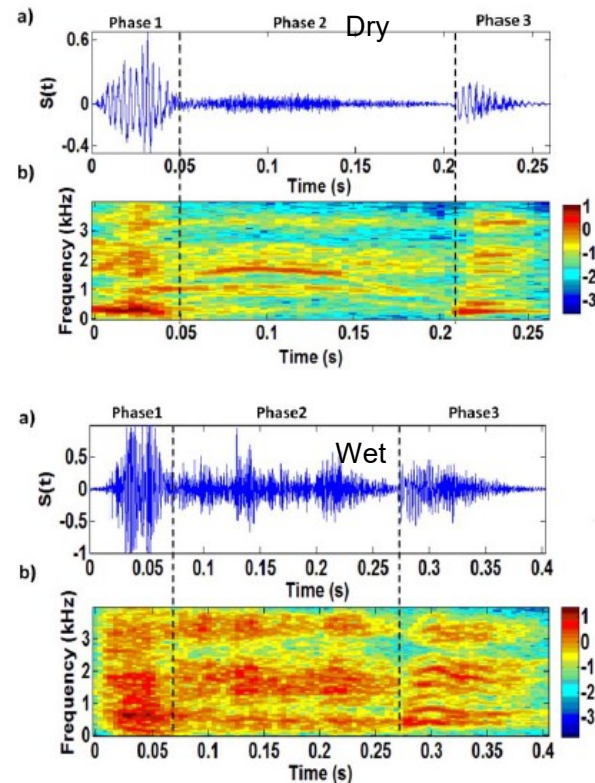
Sleep Apnea

- Sleep Apnea is a cessation of breathing of 10 or more seconds.
 - Central Sleep Apnea – no chest motion.
- With the ability to measure respiration, Machine Learning algorithms have been developed to allow detection of central sleep apnea events.



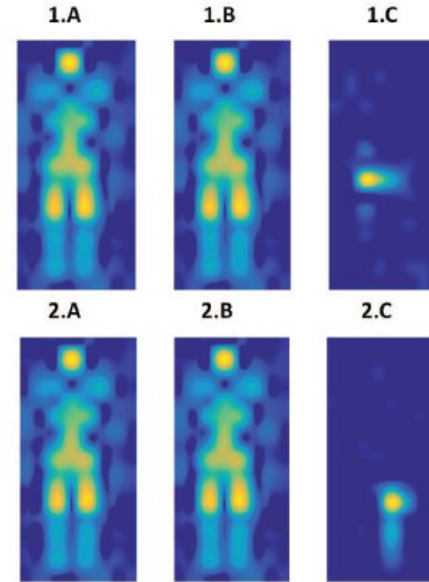
Cough - Audio

- Coughs are described clinically as wet, dry, whooping, wheezing, stridor, COVID?.
- Assessment of frequency and type
- Wet and Dry coughs have very different spectrograms
- Current work focused on distinguishing
 - cough/restricted breathing types
 - obstructive sleep apnea
 - activities of daily living



Fluid Retention

- Fluid retention is a symptom associated with Congestive Heart Failure and Renal Failure (Dialysis)
- Fluids will gravitate towards feet during day (because of gravity and standing).
- Fluids will return to torso while lying in bed at night.



400G to Bladder and thigh

Privacy and many other issues

What does this mean? Many Facets

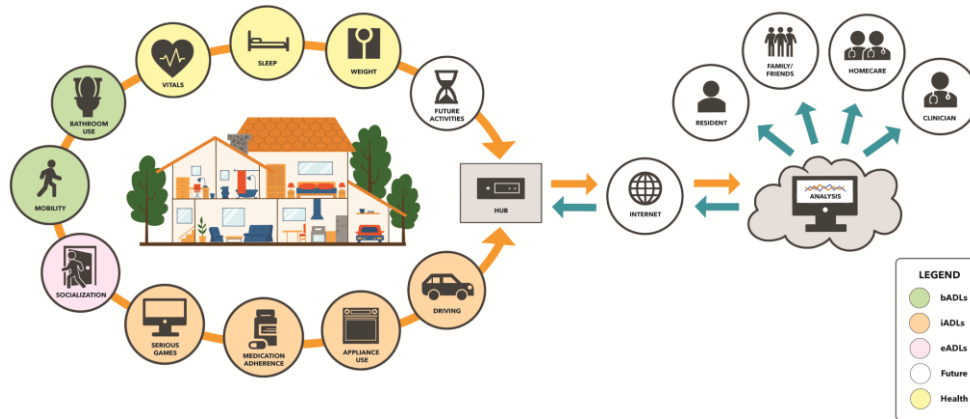
- **Beneficence:** should benefit the welfare/wellbeing of the **older adult**
- **Nonmaleficence:** should not harm (side effects, unintended consequences)
- **Autonomy:** ability to make an informed, uncoerced decision
- **Informed Consent:** having complete understanding of potential benefits and potential negative effects of an intervention
- **Privacy/Confidentiality:** ability of the **older adult** to seclude information about themselves
- **Honesty:** a facet of moral character that connotes integrity, truthfulness, straightforwardness, along with the absence of lying, cheating, theft, etc.
- **Trade-off:** a situational decision that involves diminishing or losing one quality, quantity, or property... in return for gains in other aspects.
- **Capacity:** Capacity is rarely an “all” or “nothing” issue. → Consent vs. assent?
- **Data Ownership:** → the **older adult**!

Complex: We work with companies to help them with the challenge



Bringing Assessment Home

Unobtrusive, Home-Based Assessment of Everyday Activity and Function



It is NOT just about the data

- Needs based systems
- Data → Knowledge
- Knowledge for older adult to support independence



Accessibility Standards
Canada

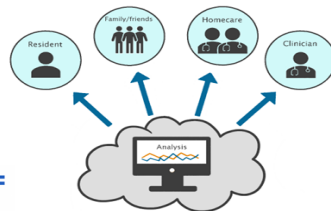
Normes d'accessibilité
Canada



lung health
foundation



Exercice | Able | Ed | Remote | Monitored



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Sensors and Analytics for Monitoring Mobility and Memory
Capteurs et analytique de suivi mobilité-mémoire

Project Partners



Future Work

Industry Collaborations

- Moving solutions forward to provide independence and well-being
- Engaged research projects

Sensing

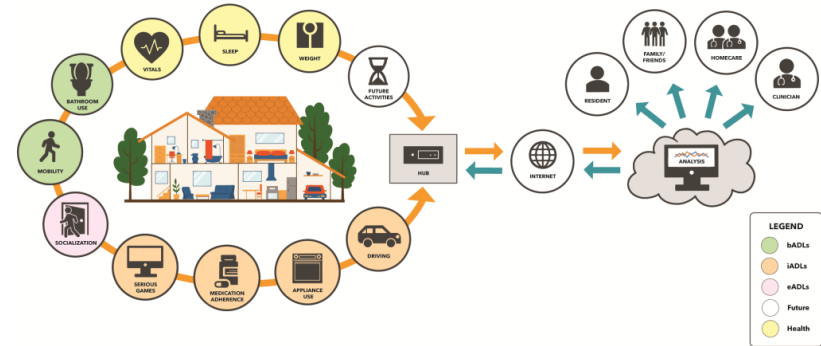
- Improved methods including fusion to increase performance

Big picture

- Knowledge through integration of the systems together (advanced AI / Deep Learning)
- Integration of solutions for ease of deployment at scale

Architecture

- Privacy: Architecture minimizing privacy invasive data leaving the home



Questions?

<https://link.springer.com/book/10.1007/978-3-031-37337-4>
eBook and Hard cover available now

Also on Amazon, Indigo-Chapters, Barnes & Noble

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